

On the Counter-jet Emission in GRB Afterglows

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Abstract. We investigate the dynamical evolution of double-sided jets and present detailed numerical studies on the emission from the receding jet of gamma-ray bursts. It is found that the receding jet emission is generally very weak and only manifests as a plateau in the late time radio afterglow light curves. Additionally, we find that the effect of synchrotron self-absorption can influence the peak time of the receding jet emission significantly.

Keywords: Gamma-ray bursts, Jets and outflows

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INTRODUCTION

According to the popular collapsar progenitor model, a double-sided jet should be launched by the central engine. However, previously in calculating the afterglow radiation, people usually only focused on the emission from the jet component running toward the observer. Recently the contribution from the jet component running backwards from us, i.e. the receding jet or counter-jet, was discussed by several authors [1, 2, 3, 4]. Especially, employing the generic dynamical model suggested by Huang et al. [5], we have brought forth detailed numerical investigations, taking into account many important effects, such as the effect of equal arrival time surface (EATS), and the effect of synchrotron self-absorption (SSA), which is decisive in radio bands [3, 4].

NUMERICAL RESULTS

For simplicity, we define the following set of parameter values as the “standard” condition: $n = 1/\text{cm}^3$, $E_{0,\text{iso}} = 10^{53}\text{ergs}$, $\theta_j = 0.1$, $\varepsilon = 0$, $\xi_e = 0.1$, $\xi_B^2 = 0.01$, $p = 2.5$, $\theta_{\text{obs}} = 0$, $\gamma_0 = 300$, and $z = 1$ (corresponding to $d_L = 6634.3\text{ Mpc}$).

In Fig. 1, we illustrate the evolution of three basic physical quantities, i.e. the Lorentz factors (γ), the half-opening angles (θ) and the shock radii (R), of the twin jets. Generally speaking, the physical quantities of the receding jet remain constant or change mildly in early stage, but evolve rapidly in a short period afterwards, usually around the time of $10^2 - 10^4\text{ d}$. It hints that the relativistic phase for the receding jet is much longer than that for the forward jet, while the semi-relativistic stage for the receding jet is much shorter. For the large circum-burst medium density case ($n = 1000/\text{cm}^3$), the receding jet is decelerated more rapidly, which means that the emission from the receding jet will peak earlier than that under the standard condition. In Fig. 2, we have shown in total ten exemplars of EATSs. We see clearly that the EATSs of the receding jet branch have much smaller typical radius, much flatter curvature and much smaller area, as compared

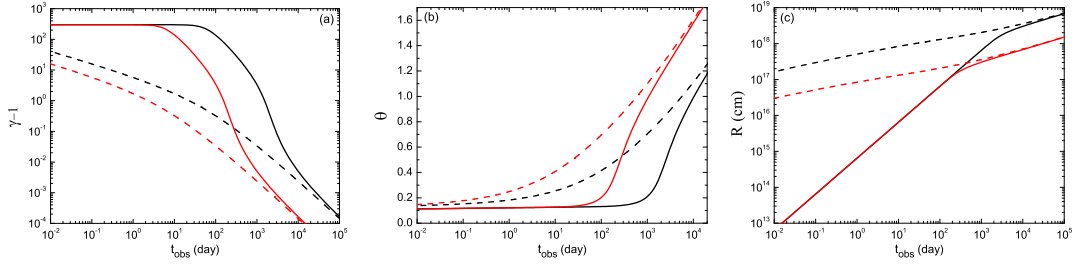


FIGURE 1. The dynamical evolution of the twin jets. In each panel, the solid line is plotted for the receding jet while the dashed line for the forward jet. The black line set refers to twin jets under the “standard” condition, and the red line set corresponds to the condition by assuming $n = 1000/\text{cm}^3$. The observer’s time (t_{obs}) has been corrected for the cosmological effect ($z = 1$).

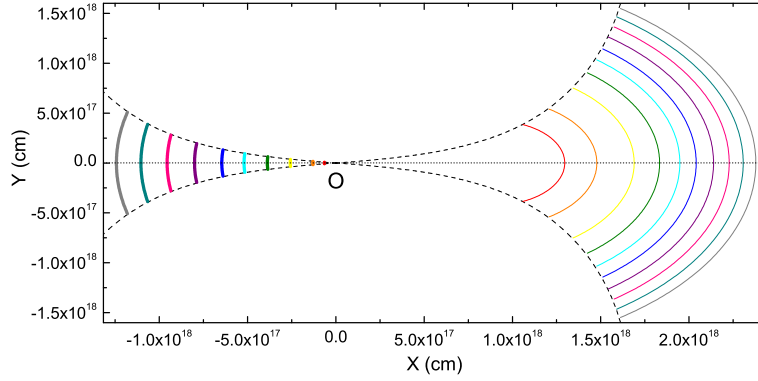


FIGURE 2. Exemplar surfaces for a “standard” double-sided jet of ten equal arrival times, i.e. 100 d (red), 200 d (orange), 400 d (yellow), 600 d (olive), 800 d (cyan), 1000 d (blue), 1250 d (purple), 1500 d (pink), 1750 d (dark cyan), and 2000 d (grey). “O” is the initiation point of the burst and the dashed lines are the jet boundaries. The thick solid lines correspond to the EATs for the receding jet branch, while thin solid lines are for the forward jet branch.

with those of the EATs of the forward jet branch, at the same observer’s time. The total light curves at multiwavelength for a “standard” double-sided jet are presented in Fig. 3. Clearly it shows that the emission from the receding jet really can contribute a significant portion in the total afterglow light curve at very late stage. Nevertheless unlike previous work by other authors [1], the receding jet emission only manifests as a plateau, not an obvious rebrightening or a marked peak. This discrepancy is mainly ascribed to the EATS effect, which can be considered only through numerical calculations [3].

We know that the peak time of the receding jet emission ($t_{\text{peak}}^{\text{RJ}}$) is relative to the time when the receding jet enters the non-relativistic phase ($t_{\text{NR}}^{\text{RJ}}$), i.e. $t_{\text{peak}}^{\text{RJ}}$ is mainly determined by dynamics [3, 4]. Therefore it should be insensitive to the observing frequency (i.e. achromatic). However Fig. 3 shows that $t_{\text{peak}}^{\text{RJ}}$ does not remain constant over a wide range of frequency, i.e. from radio to optical and X-ray. This is due to the SSA effect [4], which postpones the peak time of the receding jet emission and reduces the peak flux.

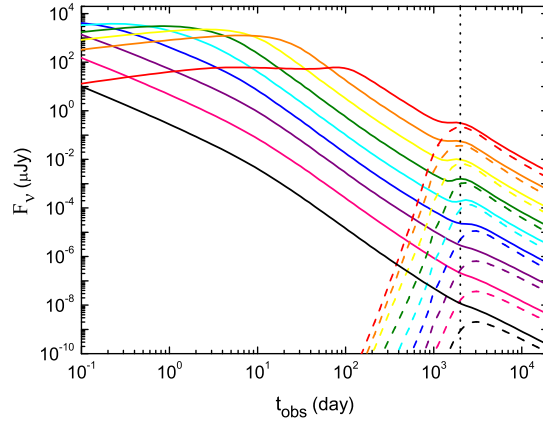


FIGURE 3. Multiband afterglow light curves including the contribution from the receding jet component. The total light curves at various observing frequencies, i.e. 10^9 (red), 10^{10} (orange), 10^{11} (yellow), 10^{12} (olive), 10^{13} (cyan), 10^{14} (blue), 10^{15} (purple), 10^{16} (pink), 10^{17} (black) Hz, are represented by solid lines, while the counter-jet emission by dashed lines. The dotted line marks the peak time of the receding jet emission at 1 GHz.

CONCLUSION AND DISCUSSION

We have studied the dynamical evolution of double-sided jets and shown that usually the emission from the receding jet makes a plateau in the late time afterglow light curves, especially in radio bands. The flux level of the plateau is usually much less than $0.3 \mu\text{Jy}$ at 1 GHz for the “standard” condition. Hence currently, the counter-jet emission is actually very difficult to observe. However, the contribution from the receding jet can be greatly enhanced if the circum-burst environment is very dense and/or the micro-physics parameters of the receding jet is different and/or the burst has a low redshift [3, 4]. In these special cases, if the host galaxy is not very bright as well, then we may be able to successfully detect the emission from the receding jet.

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REFERENCES

1. Li, Z., & Song, L. M., *ApJ*, **614**, L17–L20 (2004).
2. Zhang, W. Q., & MacFadyen, A., *ApJ*, **698**, 1261–1272 (2009).
3. Wang, X., Huang, Y. F., & Kong, S. W., *A&A*, **505**, 1213–1219 (2009).
4. Wang, X., Huang, Y. F., & Kong, S. W., *Sci. China Ser. G-Phys. Mech. Astron.*, **53**, 259–261 (2010).
5. Huang, Y. F., Gou, L. J., Dai, Z. G., & Lu, T., *ApJ*, **543**, 90–96 (2000).